ARKIV FÖR FYSIK Band 13 nr 22

Communicated 23 October 1957 by MANNE SIEGBAHN and ERIK HULTHÉN

Preliminary experiments on time-of-flight β-spectroscopy

By K. G. MALMFORS and A. NILSSON

With 1 figure in the text

SUMMARY

The properties of a provisional time-of-flight spectrometer are investigated and compared to theory. The agreement is satisfactory.

Introduction

Before designing a spectrometer according to the principles outlined in (1), it was felt desirable to check them experimentally. The double-focussing heavy particle spectrometer at this Institute was found to be suitable for this purpose owing to its high, radially decreasing field and sufficiently big dimensions. The electron source had to give an indication of the starting time of the electrons and its energy spectrum had to be discontinuous. The simplest way of meeting these requirements was to use a radioactive source giving conversion electrons in coincidence with γ-radiation. The γ-quantum could then be used as a starting time indication for the conversion electron. Of the possible methods to measure the drift times, it was decided to use (with some modifications) the oscilloscope technique developed in connection with our work on neutron spectroscopy (2).

Apparatus and source

The heavy particle spectrometer (3) has a mean radius of 40 cm, the field decreases as $1/\sqrt{r}$ (i.e. $n=\frac{1}{2}$), and a field of more than 10 000 oersteds can easily be obtained. The experimental arrangement is shown in Fig. 1. The electron pulses triggered the 517, and the γ-pulses were fed into the "delaying trigger input" of the 535. After having been delayed for some time that had to be somewhat longer than the electron drift time, they were converted into large, uniform "gate pulses" whose rising parts could be seen as a bright line on the intensity modulated sweep of 517. The time spectrum was obtained by photographing the screen of the 517. The pressure in the vacuum chamber was about 10^{-4} mm Hg; in spite of the long paths, only a minute fraction of the electrons should thus get lost by gas scattering.

The γ-detector was a plastic scintillator, 1″ thick, 2″ diam., placed outside the vacuum chamber at a distance of about 15 cm from the source. A plexiglass

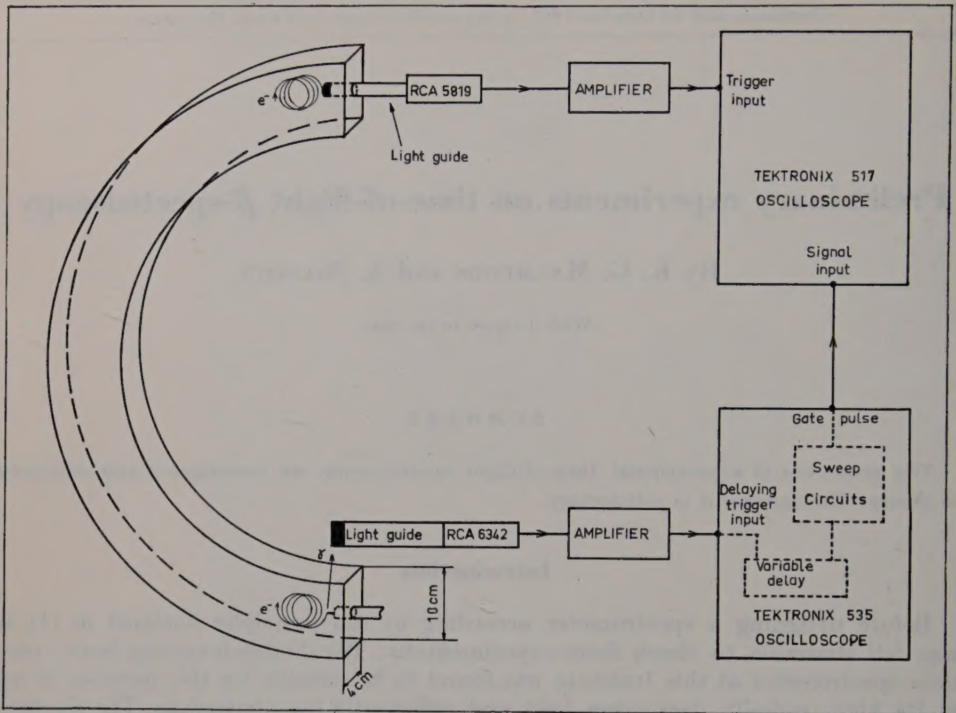

Fig. 1.

light guide brought the light from it to an RCA 6342 photomultiplier, situated outside the stray field of the magnet. The electron detecting scintillator was made of the same material, 5 mm thick, 10 mm diam., mounted to a plexiglass rod which was brought out of the vacuum chamber to an RCA 5819 photomultiplier. By means of of a vacuum belly, the whole system could be moved, thus bringing the scintillator to different points in a plane 5 cm inside the pole face.

The electron source chosen was 10 μC Bi^{207} spread over a metal filament, 6 mm long and 0.2 mm thick, which was supported by a brass rod, 10 mm in diameter, and mounted tangentially in the equatorial plane of the magnet, 3 cm inside the pole face. The main branch of the decay of Bi^{207} is the following (4): electron capture to Pb^{207}, a 1064 keV γ-transition converted to 10 %, within 10^{-10} sec. followed by a 569 keV γ converted to 2 %. Thus 3×10^5 quanta of each energy were emitted per second, together with 3×10^4 976 keV, 6×10^3 1049 keV, 5×10^3 482 keV and 1.5×10^3 555 keV electrons (the K/L-ratios being taken into account).

Experimental procedure

After ascertaining that the electron counting rate did increase when the magnet was turned on, thus indicating that the electrons got through the spectrometer, the electron-counting scintillator was moved along the symmetry axes of the vacuum chamber cross-section in order to determine the spatial distribution of the electron paths. It was then fixed in the position where the counting rate was highest, and H was varied from 0 up to 10 000 oersteds to determine the H dependence of the counting rate.

Drift-time spectra were recorded by the method outlined above, at four different fields. In order to get as high a coincidence rate as possible, the amplification in both the γ- and the electron branch was chosen so that the counting rate was about twice the zero effect. Thus, 50–80 electrons and 300–400 quanta were counted per second. The 517 sweep velocity was 0.5 μs/cm and the delay in the 535 was 3 μs. To get some information about the resolution of the spectrometer, a run was made with sweep velocity 0.05 μs/cm, delay 1.5 μs and field strength 5000 oersteds.

Results

Theory indicates that, when the scintillator is small compared to ϱ and the source is ideal, the electron counting rate should have a maximum at the point in the equatorial plane where $r = r_{\text{source}}$, and decrease linearly to zero at the chamber walls in the axial direction; in the radial direction the decrease should be almost linear also, the base width of the distribution being 4ϱ. The finite size of the detector, however, causes a broadening of the distribution measured. It should be remarked in this connection that, if the source is small, even a tiny scintillator, placed in the region of maximum counting rate, will be hit by nearly all electrons going through the spectrometer.

The theoretical predictions were confirmed experimentally apart from the fact that the radial extension was somewhat larger than expected.

As regards the counting rate as a function of H, it was practically constant from 6000 to 10 000 oersteds. Below 6000 oersteds it started to decrease with decreasing H. With an ideal source (and ideal detector), the counting rate should remain constant as long as $4\varrho <$ radial width of the vacuum chamber (for 1 MeV electrons and the width 10 cm, this means that $H > 1900$ oersteds). However, it turned out that the brass rod support of the source seriously limited the range of possible start directions of the electrons, and this effect becomes more pronounced at lower fields.

The time-of-flight exposures at different fields showed up one group that raised above the background blackening. This group moved properly when the field was changed, and it was identified as the conversion electrons from the 1064 keV transition. Those from the 569 keV transition, being about 5 times weaker, could, however, not be seen owing to the background. When plotted against H, the flight times lay on a straight line with the slope 0.13 ns/oersted. Inserting the electron energy 976 keV and the spectrometer data, and taking into account the source and detector positions, the theoretical value of the slope becomes 0.14 ns/oersted, in fair agreement with the experimental value.

The experiment at 50 ns/cm sweep velocity showed the K- and L-lines of the 1064 keV transition very well resolved, with a separation of about 35 ns (theoretically 38 ns). The film was too feebly blackened to be succesfully photometered, but the width at half maximum was certainly less than 15 ns, corresponding to an energy resolution of 2 %. A better resolution is not to be expected when $n = \frac{1}{2}$; in fact, theory predicts a rather flat time distribution with peaks at both ends and a total width of 50 ns, if ideal source and detector are assumed. However, the screening of the source by the brass support and other deviations from ideality may deform this distribution, at the same time probably reducing the transmission.

The electron counting rate was about 80 counts/second, corresponding to a transmission of 0.2 %. The theoretical value for a vacuum chamber of height = 4 cm, mean radius = 40 cm, and $n=\frac{1}{2}$, is 1.8 %. However, the brass rod support of the source stopped about 75 % of the electrons at the actual field value, thus reducing the theoretical transmission to 0.4 %. The remaining factor of 2 should not be regarded as too serious, because of the uncertainties involved.

Conclusions

The measurements here discussed are to be regarded as preliminary experiments and no far-reaching conclusions should be drawn from them. However, they generally showed good agreement with theory, thus giving encouragement to start the construction of a spectrometer based on the throchoidal orbit principle.

ACKNOWLEDGEMENTS

Our sincere thanks are due to Professor Manne Siegbahn for his interest and encouragement during the course of this work. Thanks are also due to Mr T. Appelquist for valuable technical assistance.

Nobel Institute of Physics, Stockholm 50.

REFERENCES

1. Malmfors, K. G., Ark. f. Fys. *13*, 237 (1958).
2. Malmfors, K. G., Kjellman, J., and Nilsson, A., Nuclear Instruments *1*, 186 (1957).
3. Mileikowsky, C., Ark. f. Fys. *4*, 337 (1952).
4. Alburger, D. E., and Sunyar A. W., Phys. Rev. *99*, 695 (1955).

Tryckt den 7 mars 1958

Uppsala 1958. Almqvist & Wiksells Boktryckeri AB